Office of Naval Research
End-of-the-Year Report

Publications/Patents/Presentations/Honors/Students Report

for

Grant: N00014-96-1-0056

PR Number: 96PR00857

Title: Nonlinear Signal Classification Using Dynamical Systems Theory

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OFFICE OF NAVAL RESEARCH EoY Report -- Part I
Publications/Patents/Presentations/Honors/Students Report

PR NUMBER:	96PR00857
GRANT NUMBER:	N00014-96-1-0056
GRANT TITLE:	"Nonlinear Signal Classification Using Dynamical Systems Theory"
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a).	Number of papers submitted to refereed journals:	1
b).	Number of papers published in refereed journals:	0
c).	Number of books or chapters submitted:	5
d).	Number of books or chapters published:	0
e).	Number of printed technical reports (non-refereed):	0
f).	Number of patents filed:	0
g).	Number of patents granted:	0
h).	Number of invited presentations:	3
i).	Number of submitted presentations:	1
j).	Honors/Awards/Prizes:	0
k).	Total Number of full-time equivalent Grad Students/Post-docs:	2

Grad Students: 2

Post-Docs: 0

No Female, Asian, or Minority Students or Post-Docs.

l).	Other grants recieved on this topic this year:	0

List of Specific Citations for ONR Publications/Patents/Presentations/Honors/Students Report

a). Number of papers submitted to refereed journals:

1. "A Dynamical Classification Scheme for Dolphin Acoustic Echo Location Signals", to be submitted to Intern. J. Bif. and Chaos, Summer, 1996.

c). Number of Books or Chapters Submitted:

1. Yu. Kravtsov and J. Kadtke (Eds.) Predictability of Complex Dynamical Systems (book), to be published by Springer-Verlag, Summer, 1996.

2. Kadtke, J. and Kremliovsky, M. "Detection and Classification of Signals Using Global Dynamical Models, Part I: Theory" to appear in Proc. of 3rd ONR Tech. Conf. on Broadband Signal Proc., Mystic, Conn. (July, 1995).

3. Kremliovsky, M. and Kadtke, J. "Detection and Classification of Signals Using Global Dynamical Models, Part II: Experiment" to appear in Proc. of 3rd ONR Tech. Conf. on Broadband Signal Proc., Mystic, Conn. (July, 1995).

4. Kadtke, J. and Kremliovsky, M. "Classifying Complex, Deterministic Signals", to appear in Predictability of Complex Dynamical Systems, Springer-Verlag, Summer, 1996.

5. Kremliovsky, M. and Kadtke, J. "Classification of EEG Signals from a Music Perception Experiment Using Empirical Dynamical Models", to appear in Proc.of the Intern. Work. on Nonlinear Tech. in Physiological Time Series Analysis, Summer, 1996.

h). Number of invited presentations: 3

1. J. Kadtke, "Global Dynamical Models for Bio-Medical Time Series Classification", delivered to Intern. Work. on Nonlinear Tech. in Physiological Time Series Analysis, Dresden (FRG), October 22, 1995.

2. J. Kadtke, "Global Dynamical Models for Nonlinear Data Classification", originally for the Intern. Conf. on Dynam. Sys. and Diff. Eq., declined to due scheduling conflict.

3. J. Kadtke, "Nonlinear Classificatin of Biologic Signals Using Global Dynamical Models", delivered at the Intern. Conf. on Nonlinear Dynam. and Chaos: Appl. in Physics, Biology and Medicine, Saratov, Russia, July 9, 1996.

i). Number of submitted presentations: 1

1. J. Kadtke, "A Dynamical Classification Method for Transient Marine Biologic Signals", poster, at Dynamics Days, Houston, Tx. Jan. 5, 1996.

OFFICE OF NAVAL RESEARCH EoY Report -- Part II

a). Principal Investigator: Dr. James Kadtke
b). Current Telephone Number: (619) 534 - 1726
c). Cognizant Program Officer: Dr. Michael Shlesinger

d). Program Objective: Use nonlinear dynamical systems theory and global dynamical models to develop a new nonlinear detection/classification schemes for transient, low-SNR acoustic (SONAR) signals. Eventually, develop into a working on-board classification algorithm, compatible with current Navy classification systems.

e). Significant Results During Last Year: Summary of technical results achieved since October, 1995:

1). Complete up-grade of computational resources to an IBM-Pentium based computer system using a Unix-based operating environment, to which we ported our algorithms. Also developed a 'dynamical analysis gram' interface, providing a precursor to Navy on-board dynamical Sonar analysis interfaces.

2). Theoretical model development was pursued to determine performance provided by alternate classes of dynamical models, and to derive theoretical properties of feature distributions of certain canonical data classes, such as pure noise.

3). Feature space statistical estimators were developed by adapting the formalism of detection theory to generate detection probabilities. This is the major development to date, and allows us to generate un-biased performance estimators such as ROC curves.

4). Real data analyses were performed from several sources, including: a). dolphin bio-sonar echo-location data in conjunction with NRaD researchers, yielding new quantitative evidence of dolphin neuro-physiological search patterns; b). developed a detector for very-low-SNR quasi-stationary Sonar signals, in conjunction with NADC researchers, yielding preliminary performance gains of nearly 10 dB over energy detectors; c). EEG recordings from acoustic sensory experiments supplied by researchers at the University of Tubingern, yielding a preliminary classification scheme for EEG recordings; and d). we are defining an objective, blind test designed to assess our classification performance on Sonar transient signals, supplied by researchers at NUWC, New London.

f). Plans for Next Year: During the coming year, we plan to attack the remaining tasks originally defined in the research statement-of-work. Specifically, we plan to:

a). Complete the theoretical characterization of feature distributions for the canonical signal classes, which will make rigorous several aspects of the classification performance, and provide benchmarks for later engineering development.

b). Assess the performance of more general classes of dynamical models, such as non-autonomous models tailored to non-stationary data. We also plan to derive the theoretical relation between the model features and standard nonlinear measures such as bi-spectra.

c). We plan to develop an IBM laptop, Unix-based code environment, with an advanced user-friendly interface, in order to provide a portable analysis tool which can be carried to Navy research sites for collaboration and demonstration.

d). Most importantly, we plan to continue objective data tests to provide performance assessment for real-world processing environments, and indicate areas of improvement necessary for Navy interests.

g). Graduate Students Involved in Project: Mr. Mike Kremliovsky, Mr. Aron Pentek.

Nonlinear Detection and Classification Using Global Dynamical Models

J. Kadtke, IPAPS, UCSD

Objective:

- Use nonlinear dynamical system theory and global modeling methods to develop new nonlinear signal classifiers for Sonar applications
- Develop statistical hypothesis testing structure and user-friendly interface for algorithms, to integrate into existing Navy detection/classification systems

Approach:

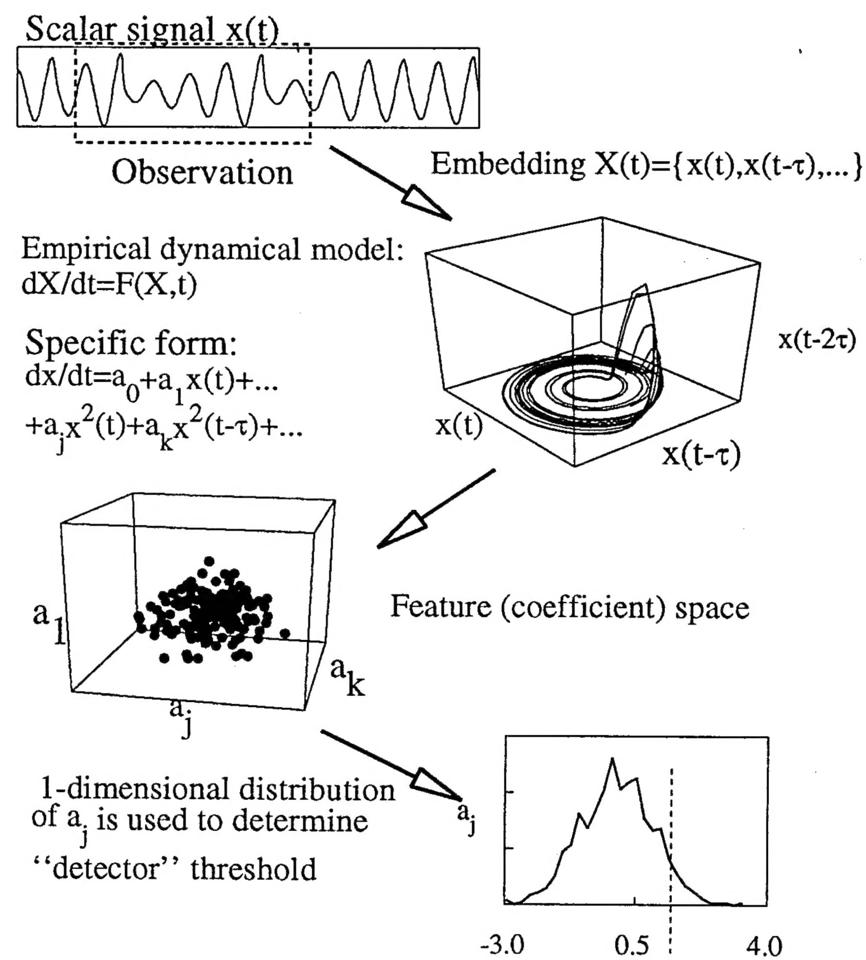
- Use sets of coupled, nonlinear ODEs numerically-fit to time-domain signals in a re-constructed, higher-dimensional phase space
- Use detection theory to develop feature space, thresholding, and probability estimators for classification statistics

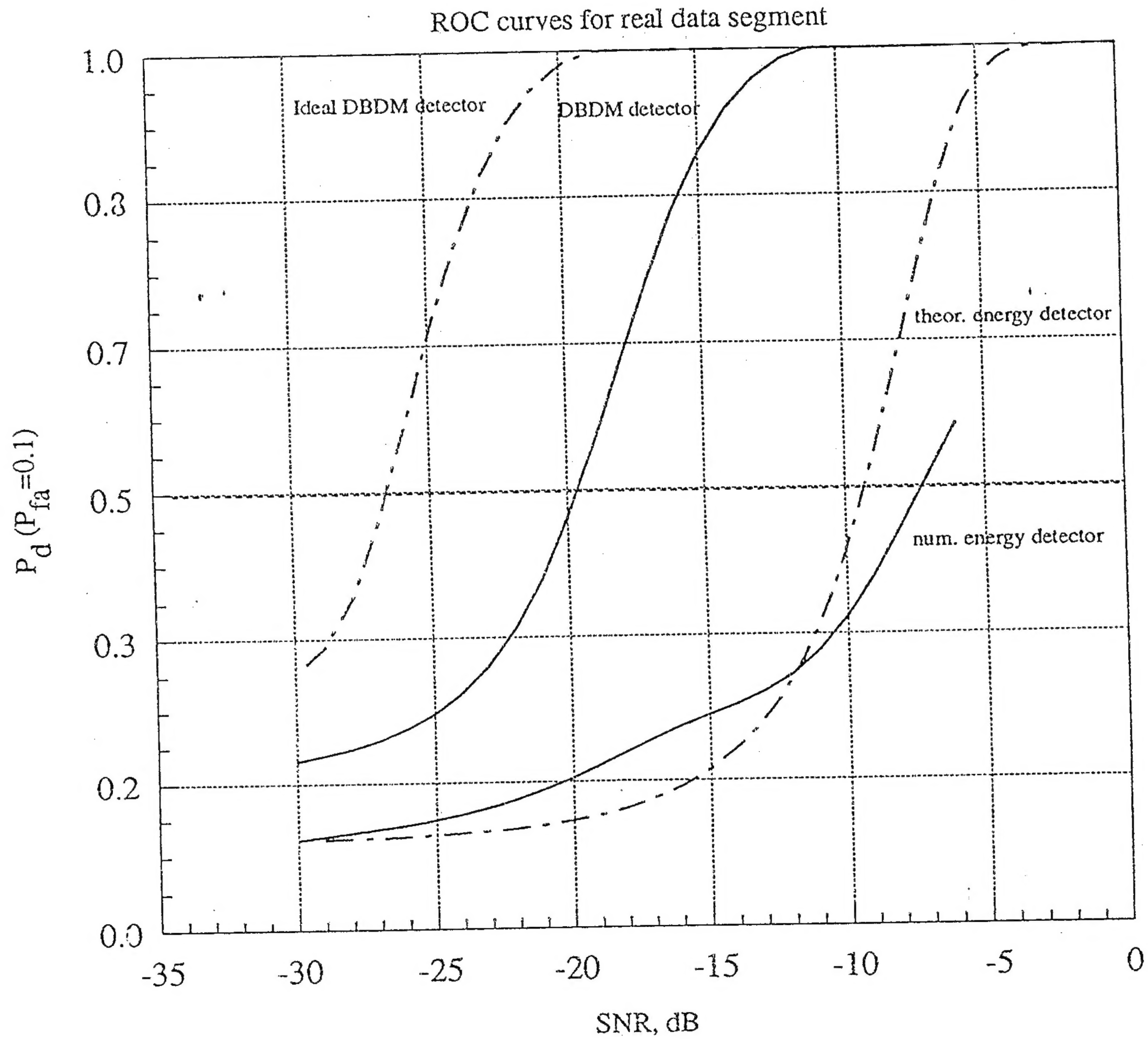
Accomplishments-to-date:

- Have implemented detection theory formalism to generate feature classification probabilities and ROC curves
- Positive results on `real` data: low-SNR, broadband Sonar; dolphin bio-Sonar; human EEG

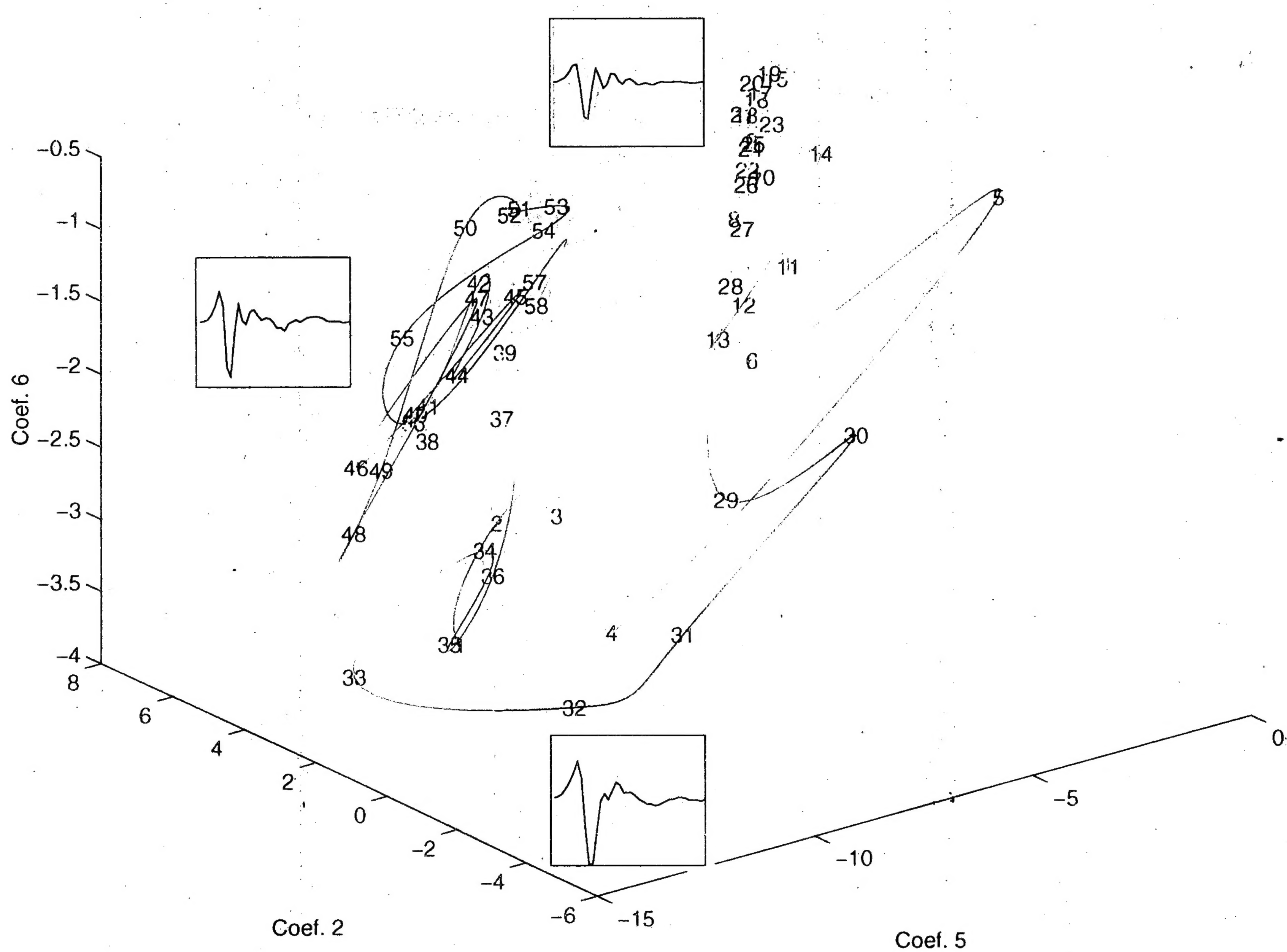
Transition and Impact:

- Collaboration with NUWC and NADC personnel to develop "dynamical gram", and assess performance on real data sets
- Collaboration with NRaD to assess performance on bio-Sonar applications, and outline future experimental investigations




ROC curves for real data segment
Ideal DBDM detector
DBDM detector
theor. energy detector
num. energy detector
1.0
0.8
0.7
0.5
0.3
0.2
0.0
$P_d\ (P_{fa}=0.1)$
-35
-30
-25
-20
-15
-10
-5
0
SNR, dB

Target 2 Clicks (5/21/91−15). dm=1. Colors Represent Coef. 4.



Supporting Vu-graphs

1. RoC curve.

This figure shows a plot of RoC curves recently obtained to assess the performance of our dynamical detection scheme on very-low-SNR, quasi-stationary, broadband Sonar signals from an open ocean test, supplied by NADC. The application here is pure detection, at the lowest SNR possible. Shown is the RoC for the dynamical detector (DBDM), and its extrapolated curve (ideal) for excellent statistics. For comparison, also shown is the RoC curve for a standard energy detector from the same data, and its theoretical (ideal) performance. The gain is nearly 10 dB, however this occurs only for certain specific signal classes.

2. Dolphin Bio-Sonar Pulse data.

This figure shows a plot of dynamical model feature distributions in the coefficient space, obtained from the analysis of outgoing active pulses from a dolphin bio-Sonar experiment done at NRaD. The data is high-SNR but very short time scale, and the application is purely classification. The dynamical technique provides a detailed characterization of the pulse structure not available with standard methods. Scientifically, the plot indicates that the dolphin tailors the pulse structure during the observation time in a systematic manner, and optimizes the pulse in a specific parameter regime. This result likely constitutes the first quantitative measurement of the dolphin's neuro-physiological search pattern, and may have implications for understanding fundamental aspects of its acoustic sensing mechanisms.